Inventory of Nitrogen Oxide Emissions and Control Technologies in Alberta's Upstream Oil and Gas Industry

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INVENTORY OF NITROGEN OXIDE EMISSIONS AND CONTROL TECHNOLOGIES IN ALBERTA'S UPSTREAM OIL AND GAS INDUSTRY

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FOREWORD

In 1987 a detailed inventory of NO_x sources was completed for the province, as part of the Acid Deposition Research Project (ADRP). This project included identification of the source and technology, location, and estimation of emissions. In 1988, Informational Letter 88-5 (IL 88-5) was jointly issued by the Energy Resources Conservation Board (now the Alberta Energy and Utilities Board) and Alberta Environment. For the first time in Alberta, this document required the use of low NO_x technology for reciprocating engines. In December 1992 the CCME issued the National Emission Guidelines for Stationary Combustion Turbines, which applied to new turbine engines. It is desired that the penetration of the technologies prescribed in these Guidelines and other low NO_x technologies be determined for Alberta.

NO_x emissions are a significant contributor to acidic deposition in the province of Alberta, as shown by recent provincial air quality modelling. Updated emissions are required every 5 years for evaluation of the situation, as mandated in the province's acidic deposition management framework document. For 1995, Alberta's emissions of oxides of nitrogen (NO_x) were more than 28% of Canada's total, and as a province ranked the highest. Of Alberta's 637 kilotonnes of estimated NO_x emissions, 256 kilotonnes were attributed to the upstream oil and gas industry, primarily for compression necessary in transportation of hydrocarbons.

As part of the work done by the Clean Air Strategic Alliance's Acidifying Emissions Management Implementation Team, a review was carried out to ensure that emission guidelines were in place for all significant NO_x emitting sectors and that cumulative emissions are not in danger of causing acidic deposition effects. The findings of this project can then be used to determine the impact of and cost effectiveness of NO_x reductions within this industrial sector.

The Air Research Users Group of Alberta Environment supported this project. The information gathered from this project will support the provincial plan for the implementation of Canada Wide Standards for particulate matter and ozone.

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LIST OF ACRONYMS

ADRP – Acid Deposition Research Program
AE – Alberta Energy
AENV – Alberta Environment
CAC – Criteria Air Contaminant
CAPP – Canadian Association of Petroleum Producers
CCME – Canadian Council of Ministers of the Environment
CH_4 – Methane
CO – Carbon Monoxide
EC – Environment Canada
EIIP – Emission Inventory Improvement Plan
EMS – Environmental Management System
EPEA – Environmental Protection and Enhancement Act
ERCB – Energy Resources Conservation Board
EUB – Energy and Utilities Board
GIS – Geographic Information System
GTI – Gas Technology Institute
MS – Microsoft
NAICC – National Air Issues Coordinating Committee
NO_x – Nitrogen Oxides
NO_2 – Nitrogen Dioxide
NO – Nitrous Oxide
N_2O – Nitric Acid
NGO – Non-Government Organization
O_3 – Ozone
PM – Particulate Matter
SCC – Source Classification Code
US EPA – United States Environmental Protection Agency
UTM – Universal Transverse Mercator
VOC – Volatile Organic Compound

SUMMARY

The purpose of this project was to estimate nitrogen oxide (NO_x) emissions for 2000 and identify the degree of penetration of cleaner technologies into Alberta's upstream oil and gas industry. The end product includes a summary report and a database of compressor engines that are regulated by Alberta Environment (AENV) under the *Environmental Protection and Enhancement Act* (EPEA).

The database was designed using MS Access. Required information was gathered from registration forms and approvals from AENV. The database was not used in the total emission estimation method. NO_x emissions from compressor engines were calculated using the total provincial volume of fuel burned by engines and an emission factor determined from previously conducted inventories. Heaters and boilers are also contributors of NO_x emissions in oil and gas operations. Although they emit fewer emissions than compressor engines and were not included in the database, they are included in the NO_x emissions estimate portion of this study.

The database includes 1852 compressor engines from 535 facilities throughout Alberta, which include sweet gas plants, sour gas plants, and compressor stations. The number of facilities represents approximately 70% of oil and gas operations regulated by AENV. It was assumed that compressor engines listed in the database were a representative sample of all compressor engines in the province. The results showed that emission-reducing technologies are used in approximately 27% of all compressor engines; 93% of compressors are reciprocating engines, while the remaining 7% are gas turbines. The NO_x emissions from Alberta's upstream oil and gas industry accounted for 255 712 t, or 10% of the national total in 1995. Using year 2000 data, NO_x emissions for the upstream oil and gas industry in Alberta were estimated to be 239 711 t.

The greatest reductions in NO_x emissions from the upstream oil and gas sector will probably be effected by the implementation of strictly low NO_x technology. Cleaner technologies are available to companies and, although all new reciprocating engines must meet a low NO_x requirement, most of the engines in operation do not incorporate this technology. This is because engines operating at a higher NO_x emission level when Informational letter 88-5 of the Energy and Utilities Board was released were grandfathered. Eventually, as old engines are replaced with cleaner ones, the NO_x emissions from operations in the upstream oil and gas sector will be reduced. Producing inventories like this one is a good method of quantifying any change in pollution emissions from specific sources and identifying the extent of penetration of cleaner engines into the upstream oil and gas sector.

1.0 INTRODUCTION

1.1 General

The purpose of this study is to estimate emissions of nitrogen oxide (NO_x) into the atmosphere by industrial processes in the Alberta upstream oil and gas sector. It has several possible practical uses – one such use might be as a comparative tool for future emission inventories. The scope of the NO_x emissions estimate is limited to devices used in the oil and gas industry. In addition to providing estimates of the mass of pollutants emitted, the end product also includes a database of compressor engines that are regulated by Alberta Environment (AENV) under the *Environmental Protection and Enhancement Act* (EPEA). The findings may be useful to several stakeholder groups such as non-governmental organizations (NGO's), governmental organizations, and oil and gas companies.

NO_x emissions are of particular interest because of the effect they can have on the environment. Acid deposition, poor air quality (smog), and ozone production in the lower atmosphere are all linked with NO_x emissions (AE, 1990). Operations in Canada's upstream oil and gas industry constitute one of the largest sources of NO_x, second only to heavy-duty diesel transport vehicles (EC, 1996).

1.2 Significance of NO_x in the Environment

Nitrogen oxides consist primarily of compounds such as nitrogen dioxide (NO_2), nitric oxide (NO), and nitrous oxide (N_2O). They are a major product of fossil fuel combustion and have the potential for adverse effects on the environment and human health. During the fuel combustion process, mostly NO is created, which is then converted to NO_2 after reacting with oxygen. NO is a highly volatile inorganic compound that has an average lifespan of about one day (Spiro and Stigliani, 1996). NO_2 is the most prevalent surrogate of the NO_x family that is generated by anthropogenic activities (US EPA, 1999).

NO_2 makes up the brownish gas, referred to as smog or photochemical pollution, which is often seen in polluted air. When NO_2 decomposes in sunlight it leads to the formation of ozone (O_3) in the troposphere. It is important to note that ozone in the troposphere can have adverse effects on human health if it is found in the ambient air we breathe. Stratospheric ozone, on the other hand, protects the troposphere and the surface environment (including humans) from ionizing solar radiation (US EPA, 1999). The problem arises when there are other pollutants in the atmosphere that lead to the build up of O_3 and NO_2. NO_2 is known to cause problems in the human respiratory tract while O_3 impairs lung function.

If NO_2 is not decomposed in the atmosphere it can be oxidized fairly quickly due to its volatility, producing nitric oxide. The oxidation of NO_x and SO_2 leads to the occurrence

of acid rain that affects many ecosystems, particularly those with a poor buffering capacity (Spiro and Stigliani, 1996). Alberta terrain has a high buffering capacity due to the relatively high concentrations of calcium carbonates found in soils and rocks. Locations where there is little carbonate in the soil and rocks to neutralize the acid experience acidification of groundwater and lakes. This is the situation in northern Ontario, where the pH of lakes has been found to be as low as 3.8. Few organisms can survive in such acidic waters, hence the terms 'dead lakes' (NAICC-A, 2000).

1.3 Natural Gas–Fired Compressor Engines

Natural gas–fired compressor engines used in the upstream oil and gas industry are of particular interest since they account for the majority of NO_x emissions from oil and gas operations. The most common use for compressor engines is natural gas transport. Compressor stations can be found along pipelines usually spaced about 80 to 160 km apart, depending on the amount of compression required to move the natural gas (US EPA, 1995). Some gas plants also require the use of on-site compressors if the wells cannot supply sufficient pressure to move the product.

All operations that are regulated by AENV are required to list their significant devices that produce NO_x emissions. The forms used to provide these data proved to be the best sources of information for the creation of a compressor engine database. Information that applied to the description of a facility and its compressor engines was included in the database so that each engine would be easy to identify. It is assumed that this data set is a representative sample of all the compressor engines used in Alberta's oil and gas fields. This means that certain inferences can be drawn from the information in the database, such as the ratio of reciprocating engines to turbine engines or the ratio of lean-burn (low-NO_x) engines to rich-burn engines. Since it is assumed that the data are representative, these inferences are expected to hold true for the entire province. Section 4 will further discuss the findings of the database and other relevant information pertaining to compressor engines.

1.4 NO_x Emission Estimate

The emission estimate performed in this study is based on fuel consumption and emission factors for compressor engines operating in Alberta. Fuel usage volumes are obtained from the Alberta Energy and Utilities Board (EUB) and previous inventories provide emission factors. With these two pieces of information, the total NO_x emissions from compressor engines in upstream oil and gas operations was determined. Section 5 will further discuss the results of the NO_x emission inventory and the methodology used.

At oil and gas facilities the only other devices that emit NO_x are heaters and boilers, both of which are less significant than compressor engine emissions. However, in estimating the total NO_x emissions from compressor engines we are also estimating the emissions

from these other sources. It is assumed that heaters and boilers consume all the fuel not used by compressor engines.

Air pollution inventories are important for keeping track of the types and amounts of emissions that are released into the environment. Given the known adverse of effects of NO_x exposure to the environment, it is desirable to document the total annual volume released into the atmosphere. There is legislation in place to protect the environment while at the same time allowing the industry to continue production. This is sometimes referred to as sustainable development, where the goal is to promote economic growth while minimizing the impact to the environment. Although EPEA does not require them, inventories can serve as tools for policymakers to produce informed decisions with respect to future NO_x emission standards and control strategies.

2.0 AIR POLLUTION INVENTORIES

2.1 General

Several inventories have been conducted in Alberta in past years, some pre-dating the EPEA and others that are more recent. The methodology can differ a great deal between inventories that are conducted by different organizations. This can lead to different results from inventories that are conducted over the same variables such as the year or the region of study. An example of this is inventories prepared by Environment Canada (EC) (1996) and the Canadian Association of Petroleum Producers (CAPP) (1999) inventories, both done for the 1995 base year. The focuses of the two inventories were different but they both reported total NO_x emissions from the upstream oil and gas industry. The reported values differed by more than 23 000 t of NO_x. The two studies used different methodologies and assumptions and the results would therefore be expected to differ, as can be expected for the results of this study. Although there are no year 2000 inventories with information on Alberta's upstream oil and gas industry, there are several older inventories against which the results can be compared. In fact, they might serve as useful references for checking the accuracy of the results of this report.

2.2 Environment Canada: Criteria Air Contaminants

In 1998, Environment Canada released an inventory of Criteria Air Contaminants (CACs) from all provinces for the 1995 base year. The inventory is based on both point sources and area sources and included the following pollutants: total particulates (PM), particulate matter with a diameter less than 10 micrometres (PM_{10}), particulate matter with a diameter less than 2.5 micrometres ($PM_{2.5}$), sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC) (EC, 1995; EC, 2000).

Environment Canada has a mandate to release inventories as such every five years. The previous CAC inventory was conducted for the 1990 base year and the next one will be for the 2000 base year. The result of the CAC inventories showed that sources in Alberta emitted 486 713 t of NO_x in 1990 and 636 996 t in 1995. The increase within the five-year period is by approximately 25%, almost all of which is attributed to industrial processes (98%). Several new categories were added in 1995 and, although it is not disputed that there was an increase NO_x between inventories, it should be noted that there are other possibilities such as improved estimation and monitoring techniques and more industries to oversee. For the 1995 base year, Alberta's upstream oil and gas industry accounted for 10.4% of the national NO_x emissions, most of which was attributed to compressor engines and totalled 255 712 t.

Figure 1 shows the NO_x emissions in 1995 for each Canadian province as taken from the Environment Canada - CAC (1996) emissions inventory. Alberta emits more NO_x than any other province in Canada, followed by Ontario, Quebec, and British Columbia. Half

of the NO_x emissions in Alberta are from the industrial sector (CAC, 1996). Incidentally, the upstream oil and gas industry accounts for 78% of that sector in Alberta. The major source of NO_x emissions in Ontario and Quebec is transport. This seems reasonable since there are larger populations in those regions.

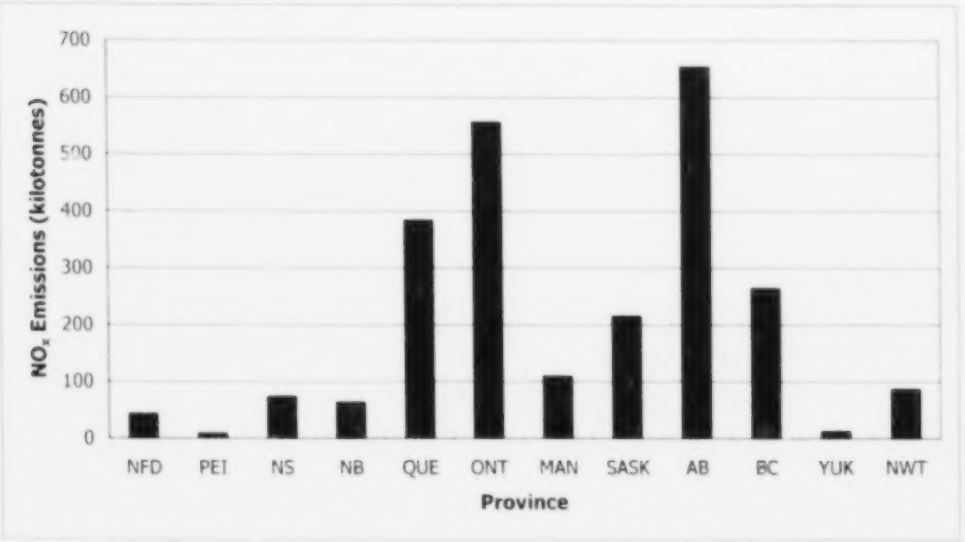

Figure 1 Provincial NO_x Emissions in 1995 (CAC, 1998)

2.3 Canadian Association of Petroleum Producers

In 1999, CAPP released an inventory of its own documenting methane (CH_4) and volatile organic compound (VOC) emissions from the upstream oil and gas industry in Alberta for the 1995 base year. CAPP is an association that has 170 member corporations whose focus is on the exploration, development, and production of petroleum products. The report looks at the types and sources of pollutants and, although the focus is CH_4 and VOC, there are some representative data regarding inorganic compounds such as NO_x and CO. The following equation (1) shows how emissions were calculated in the CAPP report:

Equation 1:

$$ER_k = Q_{Fuel} \times EF_k \times (1.0 - CF)$$

Where,

ER_k	=	Emission rate of pollutant k (kg/y)
Q_{Fuel}	=	Average volumetric rate of fuel consumption ($10^6 m^3/y$)
EF_k	=	Average uncontrolled emission factor ($kg/10^6 m^3$)
CF	=	Control factor (fractional control efficiency)

Although some of the NO_x emission data were taken from the 1995 EC CAC emissions report, simply becoming familiar with the methodology employed in the report can prove useful. The report is an excellent source of information with regard to the emission factors.

Variables included average volumetric rate of fuel consumption, average uncontrolled emission factor, and control factor. CAPP reported that reciprocating engines emitted 45 500 $kg/10^6 m^3$ while gas turbines emitted 5 725 $kg/10^6 m^3$. These numbers indicate the number kilograms of NO_x emitted for every million cubic metres of gas burned. These values are emission factors that were used by CAPP. The NO_x emission estimate for the upstream oil and gas sector was reported to be 232 048 t in 1995.

2.4 Alberta Environment: NO_x Emissions for Alberta

Alberta Environment released two reports focused on estimating NO_x emissions from all sectors in Alberta (AENV, 1990; AENV, 1988). The first report, released in 1988, includes data from 1981 to 1985 while the second report is only for 1987. The methodology AENV used for estimating NO_x emissions from compressor engines is very similar to that used in this study. The two variables used were emission factors and the volume of fuel burned by compressor engines. Also, since these reports show the emissions from compressor engines over a lengthy time period, they should prove to be very helpful as comparisons to the data derived in this study. AENV found that reciprocating engines emitted 55 400 $kg/10^6 m^3$ while turbine engines emitted 4 700 $kg/10^6 m^3$. These numbers are emission factors and indicate the number kilograms of NO_x emitted for every million cubic metres of gas burned. The emission factors used by CAPP, as noted above, are taken from the fifth edition of the US EPA AP-42, while the values AENV used were taken from the fourth edition. The NO_x emission estimate for the upstream oil and gas sector was reported to be 233 400 t in 1988.

2.5 Acid Deposition Research Program

The Acid Deposition Research Program (ADRP) produced an inventory focused on emissions of sulphur dioxides and nitrogen oxides in Alberta in 1985. The premise of the

report was simple—in order to predict the quality of air in Alberta an inventory of sources and pollutants would be required. The ADRP inventory is now outdated but can still be used as a guideline for future reports that cover the same type of data. Also, trends in emission volumes and the type of technology in use can be seen over time. The scope was not limited to industrial sources but also included urban centres and major transportation motorways. By taking into account all these sources, both stationary and mobile, it was possible to achieve a very comprehensive look at the state of the province-wide air quality. The project included several goals: identification of the source, technology, and location and estimation of emissions (ADRP, 1987). The methods used in the study included identifying anthropogenic sources, characterizing them, determining their contribution, and then inserting them into a database for easy reference. The major fields used to characterize emission sources were: type of emission, geographic location, environmental setting, physical geography, maximum licensed emission rate, and emission characteristics. Equation 2 shows how emissions were calculated in the ADRP report:

Equation 2:

$$ER = MP \times LF \times TE \times EF \times OT \times 24 \times 10^{-12}$$

Where,

ER	=	Emission rate (t/d)
MP	=	Maximum rated power (kW)
LF	=	Load factor
TE	=	Thermodynamic efficiency (kJ/kW-h])
EF	=	Emission factor (ng/J)
OT	=	Operating time factor (range of 1.0 to 0.0)

Since the ADRP report also took into consideration the emissions from compressor engines, it can be a valuable tool in assessing a methodology for estimating NO_x emissions. Through the use of emission factors and several other variables such as operating time, maximum rated power, load factor, and thermodynamic efficiency, the authors were able to estimate the average rates of NO_x emissions from compressor engines (ADRP, 1987).

3.0 NO_X EMISSION CONTROLS

3.1 General

Natural gas–fired compressor engines are stationary internal combustion sources as described by the US EPA in AP-42 (US EPA, 1995). Compressor engines are primarily used for transport of natural gas through pipelines. They are required at regular intervals to recompress the gas in the pipeline to supply the driving force to keep it moving. Compressor engines can be broken down into two types: reciprocating and gas turbines. Reciprocating engines are much smaller but far more common in the oil and gas sector. Figure 2 is a representation of the ratio of reciprocating compressors to gas turbines. Gas turbines are much larger and require more power to operate. Heaters and boilers are smaller sources of NO_x emissions but in order to prepare a complete inventory they must be included.

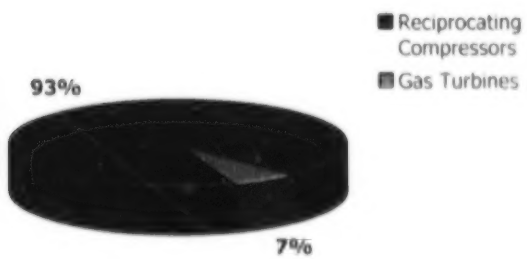

Figure 2 Distribution of compressor engine types in Alberta's upstream oil and gas industry

NO_x emissions are derived primarily as by-products of combustion systems (Karell et al, 1991). The US EPA assigns Source Classification Codes (SCC) to the processes that these systems use from which corresponding emission factors can be determined. Some emission factors quantify the volume of pollutant released per volume of fuel burned based on the technology in question. There are variations to the emission factor depending on the type of emission control equipment in use. Low NO_x is the only engine specification reported to AENV and is defined as an engine that has an emission factor below 6 g/kW-h.

3.2 Standards and Guidelines

AENV regulates and manages NO_x and SO_2 emissions and adheres to the Alberta *Environmental Protection and Enhancement Act* (EPEA). The goal of AENV is to ensure that emissions from all industries are minimized to protect human health and the environment. Alberta Energy and Utilities Board (EUB) is another regulatory body in Alberta and is responsible for ensuring that energy resources are developed in a safe, efficient, and environmentally responsible way. Depending on their size and estimated emissions, many oil and gas facilities apply directly to the EUB for operating approvals and do not report to AENV at all.

In 1996, AENV released the Code of Practice for compressor and pumping stations and sweet gas processing plants. This code specified a low NO_x requirement for reciprocating engines regulated by AENV. The current emission requirements for compressor engines in Alberta are described in 'IL 88-5: Application for Approval of Natural-Gas Driven Compressors', which set standards for low NO_x emission technologies (ERCB, 1988). It stated that all new facilities where compression is needed are required to implement low NO_x technology. This included any expansion of existing facilities but was limited to compressor engines larger than 600 kW.

In 1995, the Canadian Council of Ministers of the Environment (CCME) decided to use the same standards as those listed in IL 88-5. The standard is, as of 1995, the national guideline for emissions for reciprocating compressor engines that are natural gas-driven as part of the national NO_x/VOC Management plan (Macdonald and Bietz, 1996).

3.3 Reciprocating Compressor Engines

Reciprocating compressor engines are by far the most commonly used engine type for product transport. They are used primarily at pipeline compressor and storage stations and at gas processing plants. Due to the effects of friction losses in the pipeline, reciprocating engines are required to raise the discharge pressure for continued transmission (US EPA, 1995). A reciprocating compressor engine can range from 40 to 8000 kW but usually does not exceed 2000 kW. For this reason it is assumed that all compressor engines contained in the database with a rating below 2000 kilowatts are reciprocating engines. The average rating for reciprocating compressor engines in the database was found to be approximately 720 kW; not many came close to the 2000-kW level.

Reciprocating compressor engines account for 93% of all engines in Alberta. Of these, only 24% are low NO_x engines. The average emission factor for reciprocating engines not using low NO_x technology is approximately 21 g/kW-h. This is very high considering that low NO_x technology has an emission factor below 6 g/kW-h. There are several types of reciprocating engines: 2-cycle lean burn, 4-cycle rich burn, and 4-cycle lean burn. Since this information is not provided some assumptions were made: low NO_x reciprocating engines are considered to be 4-cycle lean burn and the remainder are

considered to be 4-cycle rich burn. These assumptions are relevant for determining the SCCs listed in the database, which are further discussed in section 3.4. Figure 3 is a representation of the ratio of rich-burn engines to lean-burn engines in Alberta's upstream oil and gas sector.

Figure 3 Distribution of technologies used in reciprocating compressor engines in Alberta's upstream oil and gas industry

There are several different makes of reciprocating compressor engines that are predominantly used in Alberta. Approximately 42% of the engines are manufactured by Waukesha, which is a Dresser company. Other popular makes are White Superior and Caterpillar, accounting for 23% and 15%, respectively. Cooper also has a fairly significant share of the market with 6% of all engines. The remaining 14% of reciprocating compressors are comprised of several different manufacturers such as Ajax, Clark, Cummins, Fairbanks, and Ingersoll; each of which account for less than 2% of all engines.

3.4 Gas Turbines

Gas turbines can be used for several applications but for the purposes of this study the focus will be on their role in natural gas transmission. Turbines of all types have an average power rating of 29 977 kW (US EPA, 1995). The average value calculated for this study is 8815 kW. When reporting information to AENV, companies do not have to differentiate between reciprocating and turbine engines; therefore it is assumed that all engines that have a rating above 2000 kW are gas turbines.

Gas turbines account for approximately 7% of engines used in Alberta, of which 77% employ low NO_x technology. Figure 4 is a representation of the ratio of low NO_x gas turbines to regular gas turbines in Alberta's upstream oil and gas sector.

Figure 4 Distribution of technologies used in gas turbine engines in Alberta's upstream oil and gas industry

The most predominant manufacturers of gas turbines used in Alberta are Solar, Rolls Royce, and Cooper. Solar is the most common make of gas turbine, being responsible for 42% of gas turbines in Alberta. Rolls Royce has 18% of the market share while Cooper has 16%. The remaining 24% of gas turbines are made by several different manufacturers such as General Electric, European Gas Tornado, and Allison; each of which accounts for a small proportion of all engines.

3.5 Heaters and Boilers

Heaters and boilers are the third source of NO_x emissions from the upstream oil and gas industry. Some operations do not use heaters or boilers. For example, gathering systems have no need for heaters and boilers since their sole purpose is to collect product. On the other hand, heavy oil and crude bitumen production have no need for compressors and devote all their spent energy to heaters and boilers. Heaters and boilers emit far less NO_x than do reciprocating compressor engines and are usually only present at plants and batteries.

For the purposes of this study, heaters and boilers were not documented in the database. It is assumed that all fuel not used by compressor engines is used by heaters and boilers. Using the appropriate emission factor, the emissions from heaters and boilers could be assessed since the amount of fuel they used was known. The emission factors used by CAPP (1999) for heaters and boilers are identified by their size; greater than 30 MW, 3 to 30 MW, and less than 3 MW. However, since they were not documented in the database they could not be qualified by each grouping. An average emission factor for the three size groups was used in the emissions estimate as adapted from CAPP (1999). The calculated value was comparable with the emission factors used by the ADRP (1987), the US EPA (1985), and Alberta Energy (1990) (Table 1). Since all significant emitters of NO_x from the upstream oil and gas industry will be included, the emission inventory will be more comprehensive and reliable.

Table 1 NO_x Emission Factors Used in Previous Studies ($kg/10^6m^3$)

	CAPP, 1999	AE, 1990	AENV, 1990	ADRP, 1987	USEPA, 1985
Reciprocating Compressor Engines	**45 500**	55 500	55 400	40 313	55 500
Gas Turbines	**5 725**	4 725	4 700	4 013	4 725
Heaters and Boilers	**4 213**	3 713	3 700	3 713	3 713

3.6 NO_x Emission Factors

Estimating the emissions of a specific pollutant requires the use of an emissions factor (EIIP, 1999). The US EPA assigns SCCs to processes that specific technologies use, all of which have designated emission factors that can be retrieved from AP-42 (US EPA, 1995). Table 2 contains the codes that are relevant to this study. Emission factors are employed to quantify the output of a pollutant based on the type of input and the type of technology. They are usually expressed as a ratio; for the purposes of this study, the units used are kilograms per million cubic metres. This means that for every million cubic metres of fuel input, a certain mass of NO_x will be released.

Table 1 shows emission factors used in previous studies. There are only three per study, one for each type of device used in the upstream oil and gas sector. Some of the other studies used several emission factors for each type of device depending on its size. CAPP (1999), for example, used three emission factors for heaters and boilers to account for their size difference. For the purposes of this study, those three values were averaged, making the assumption that each size category was equally distributed. There was insufficient information available within the scope of this project to account for such discrepancies, which are assumed to be minimal considering that heaters and boilers are not the major source of NO_x emissions in the oil and gas sector. The values used for this study those highlighted in Table 1, which are taken from the CAPP (1999) emissions inventory.

Table 2 US EPA Source Classification Codes for Gas Turbine and Reciprocating Compressors (SCC3 Description: Industrial, SCC 6 Description: Natural Gas)

SCC	SCC1 Description	SCC8 Description	Pollutant	Control
20200201	Internal Combustion Source	Turbine	Nitrogen Oxides	UNCONTROLLED
20200202	Internal Combustion Source	Reciprocating	Nitrogen Oxides	UNCONTROLLED
20200252	Internal Combustion Source	2-cycle Lean Burn	Nitrogen Oxides	CLEAN BURN
20200253	Internal Combustion Source	4-cycle Rich Burn	Nitrogen Oxides	UNCONTROLLED
20200254	Internal Combustion Source	4-cycle Lean Burn	Nitrogen Oxides	UNCONTROLLED

Emission factors can vary depending on more specific details about the technology in use. For instance, reciprocating compressor engines can be differentiated by the number of cycles (two or four) and the type of burn (rich or lean), each of which would have a different emission factor. The information required to make this distinction is not provided to AENV; therefore using a general emission factor for each type of device was justified. The emission factors used by CAPP were originally derived from AP-42 (US EPA, 1995). Several other emission factors were used in the previous inventories listed in section 2; however, most of the data from these reports was taken from the 1985 version of AP-42. Since the 1985 version is outdated and the current version was the one used by CAPP, it was assumed that the emission factors used in this report are accurate and up to date.

3.7 Emission Control Technologies

Emission control technologies are used to reduce the amount of pollutants being released by a device. They can be add-on technology such as selective catalytic reduction or they can possess the technology as part of their operating system (EIIP, 1999). Table 3 shows the most common types of technologies used in the oil and gas industry. The most common is the use of low NO_x technology. It is required that all new compressor engines in Alberta possess low NO_x technology as per the EUB Informational Letter 88-5 (ERCB, 1988). NO is created in the engine during the combustion process. This NO molecule will easily react with the oxygen molecules found in the atmosphere leading to the formation of NO_x (GTI, 2002).

Table 3 Available Emission Reduction Technologies

Reciprocating Compressors	Gas Turbines
Dry Controls (Air-to-Fuel Ratio)	Dry Controls (Air to Fuel Ratio)
Wet Controls (Steam or Water Injection)	Wet Controls (Steam or Water Injection)
Pre-Stratified Charge / Clean-Burn Cylinder Head	Post Combustion (Selective Catalytic Reduction)
Post Combustion (Selective Catalytic Reduction)	
Post Combustion (Non-Selective Catalytic Reduction)	

For a reciprocating compressor engine to be considered low NO_x, the combustion process is in low excess air to limit the temperature. This is usually referred to as the air-to-fuel ratio (A/F) that is found in the combustion mixture. Engines use different A/F values; if the amount of air is below the level required for stoichiometric conditions then the A/F ratio is referred to as fuel-rich. On the other hand, if the A/F is above that level, the A/F is referred to as fuel-lean. Stoichiometric conditions indicate complete combustion by using the minimal amount of air required for sufficient oxygen to be supplied (GTI,

2002). A 4-cycle rich-burn compressor engine would use a fuel-rich A/F ratio while a 4-cycle lean-burn engine would use a fuel-lean A/F.

A second control method for reciprocating compressor engines utilizes either a pre-stratified charge or clean-burn cylinder head design. The pre-stratified charge is a retrofit system for 4-cycle rich-burn engines where the air is introduced into the intake manifold in controlled amounts. Clean-burn cylinder head designs employ the same principle as the pre-stratified charge but cannot be retrofitted to an existing engine.

Gas turbines also utilize NO_x reduction technology, in fact, far more often than do reciprocating compressors. The primary source of NO_x emissions from turbines is thermal oxidation of nitrogen in the combustion air. This means that in order to control the emissions from turbines, the combustion conditions need to be controlled. Two types of controls in turbines are lean combustion and lean premixed combustion (GTI, 2002). Lean combustion refers to excess air in the combustion chamber to reduce the flame temperature, thus reducing the thermal oxidation process. The second method refers to the use of a premixed solution of fuel and air (GTI, 2002).

Injecting water or steam into the flame area creates a heat sink inside the combustion chamber, lowering the temperature and preventing ionization of the nitrogen (GTI, 2002; US EPA, 1999). This is another low NO_x control method that is not related to the A/F and can be applied in both turbines and reciprocating compressor engines.

Post-combustion controls are the last type of reduction technology used in the oil and gas industry. The most common are non-selective catalytic reduction (NSCR) and selective catalytic reduction (SCR). Gas turbines and lean-burn compressors only use SCR while rich-burn compressor engines can use either. By introducing a catalyst in the exhaust stream of an engine, certain pollutants can be removed. The only difference between the two is that SCR targets specific pollutants for removal while NSCR is sometimes referred to as a three-way catalyst because it reduces NO_x, CO, and HC simultaneously into H_2O, CO_2, and N_2.

There are several emission control technologies available on the open market; some reduce emissions more than others while some are far more expensive. Reciprocating compressor engines are responsible for the majority of emissions in the oil and gas industry, but if they are equipped with a control technology as listed above, a significant reduction in the NO_x emissions is possible.

4.0 COMPRESSOR ENGINE DATABASE

4.1 Methodology Used for Database Design

The desired format for the compressor engine database was Microsoft Access. The database contains a wide variety of information ranging from facility location to its EPEA Approval Identification Number. Table 4 lists the field headings used in the database. The facility information is reported to Alberta Environment in several formats depending on the type and magnitude of the operation. Because of this multilateral reporting there are several sources of information available. Since the second objective of this study is to estimate the NO_x emissions from compressor engines, the database also contains some pertinent information for the estimation method.

Table 4 List of Field Headings Used in the Compressor Engine Database

Administrative Information	Device Information	Location Information
Operation ID	Device Code	Municipality
Operation Name	Device ID	Region
Operation Status	Device Name	Latitude
Status Date	Power Rating (kW)	Longitude
Approval ID	Low NO_x	Meridian
Approval	Emission Factor (g/kW-hr)	Range
Amendment	Reported NO_x Emission (t/d)	Township
Approval Type	Calculated NO_x Emission (t/d)	Section
Approval Status	Process Code	Quarter Section
Organization Name	Process ID	Legal Subdivision

4.2 Types of facilities

There are three types of oil and gas operations that are regulated by AENV that operate compressor engines. These are compressor stations, sweet gas plants, and sour gas plants. Compressor stations follow a code of practice and are required to submit a registration form in order to operate. Sour gas plants must apply for an approval and often have several operating conditions imposed on them. Sweet gas plants must follow a code of practice, however, under certain circumstances must apply for an approval. This variation is attributed to the method of wastewater disposal. To differentiate between the two types of permits they will be referred to as approved and registered facilities. The compressor engine database does not classify facilities by the type of operation or permit that it possesses.

4.3 Sources of Information

Alberta Environment makes available to the public much of the information about approved and registered facilities. There is an on-line Approval Viewer (AENV, 2002) that allows members of the public to view the terms and conditions to which each facility must adhere. The registered facility information may be requested on a per facility basis from AENV but is not available through a viewer; however, the Code of Practice requirements can be accessed at the Alberta Government Queens Printer website (AB, 2002). Approved facilities also have resumes that are prepared by AENV based on information in the approval application. The resume summarizes the planned operations for the facility. Along with the resume comes an Air Emissions Branch Attachment, which details the devices in use at the facility. Types of devices can include heaters, boilers, dehydrators, and compressor engines. Since NO_x emission information is not contained in the approval, resumes were retrieved for the required data. Registration forms are very similar to resumes and were also retrieved for all registered facilities. Example registration and resume forms can be found in the appendix (Example Forms 1 to 3). Table 5 shows the approximate total number of facilities that are either approved or registered with AENV as of December of 2001.

Table 5 Number of Oil and Gas Facilities Contained in the Compressor Engine Database of Those Regulated by AENV

	Facilities in database	Total facilities	Percent found
Approved facilities	261	275	95%
Registered facilities	274	506	54%
Total	535	781	69%

Facilities in the compressor database account for approximately 70% of those that are regulated by AENV (Table 5). The errors stem from unavailable and misreported information. Data from registered facilities that had approvals before EPEA was implemented in September of 1993 were unavailable. When it came time for these facilities to switch from the approval to the registration, they simply referred to their old approval rather than fill out any device information on the registration form. Unfortunately their old approval did not contain any device information and in most cases the resume attachment was unavailable. Facilities that emit less than 16 kg/h NO_x are regulated by the EUB. All other compressor engines in Alberta are reported to the EUB and it is assumed that this database contains a subset of all compressor engines in Alberta since all engines registered or approved by AENV are also reported to the EUB.

4.4 Database of Compressor Engines

The database was created using Microsoft Access; however, there were some interim steps leading up to that point. Many of the administrative data for each operation were entered into the AENV database called Environmental Management System (EMS). EMS is an Oracle-based database that is currently used for all types of operations that are reported to AENV. EMS contains location coordinates in UTM and in Legal Land Description. It contains information about the operation name, date, status, and approval information. As a first step towards building the compressor database, EMS was updated by entering some device information that was reported on the registration and resume forms. The required information from EMS was imported into an MS Excel spreadsheet prior to using MS Access.

In MS Excel the data are viewed on a single flat sheet. Because of this, they are easily sorted, updated, and normalized. Not all of the required information was entered into EMS and the remaining data had to be entered manually into EMS for each device. This information was primarily NO_x data such as emission factors and reported emission rates. The make and model and the power rating of the compressors were entered into EMS. Once the data table was completed, it was split into two before being imported into MS Access for the final steps of the database creation.

Given that one facility can have multiple devices, the table in MS Excel was broken down into two tables, one with 535 facility entries called 'Operation' and the other with 1852 device entries called 'Device'. The primary key in the operation table is the Operation Identification Number while the primary key in the device table is the Device Identification Number. Both of these numbers are assigned by EMS upon creation of a new entry; they are unique to the record and are used in the compressor database as identification keys. Since the data were normalized in MS Excel before being imported, referential integrity was established between the two tables, which are linked by the Operation Identification Number. Once the relationship between two tables is established with referential integrity, any new data entries or existing data editing must be consistent between the two tables, otherwise an error will occur and MS Access will not allow any updates. The relationship between these two tables is one-to-many. There is a third table in the database called 'SCC', which has a relationship with the device table only.

SCCs are discussed in section 3.0. There are five different codes that can be associated with NO_x emissions and compressor engines, depending on the information provided. There is only one code for turbine engines while the other four are related to reciprocating engines. Since not all the information may be known, there is a general code for reciprocating engines while the other three are specific with regard to the type of technology in use.

There are several other emission factors for compressor engines, which are not included because they take into account emission reduction technologies such as catalytic reduction or pre-combustion chambers. This information is not usually reported to AENV and therefore cannot be determined without evaluating each engine individually

which is beyond the scope of this project. The third table is static and is associated with the device table only by the SCC number. The significance of this table is minimal as it only provides some additional technological information about compressors.

The information contained in this database is a sample of all the compressors in operation throughout Alberta. It is a significant sample and is assumed to be representative of the entire oil and gas industry.

4.5 NO_x Emission Data

The database includes four data fields related to NO_x emissions. The first is the reported volume of daily emissions. The second is the calculated volume of daily emissions. Equation 3 shows the method used to calculate emissions in tonnes per day.

Equation 3:

$$ER = RP \times (EF \times 24) / (1 \times 10^6)$$

where,

ER	=	NO_x emission (t/d)
RP	=	Rated power (kW)
EF	=	Emission factor (g/kW-h)

Note: emission factor multiplied by 24 to convert hours to days
equation divided by 1×10^6 to convert grams to tonnes

The calculated emissions field was added after the data were compiled to serve as a check. A significant discrepancy was found between the reported emissions and the calculated emissions when they were summed up. The difference was assumed to be due to misreporting, which was attributed to miscalculations or errors during the data entry (i.e, misplaced decimal). The apparent errors were removed to normalize the data and to put the information into a usable form. For example, if a company reported its emissions to be 0.14 t/d but the calculated emissions were found to be 1.4 t/d, the reported value was corrected. Once the data were normalized, discrepancies between the calculated and reported values were attributed to rounding.

The third data field related to NO_x emissions is the emission factor. AENV requires that companies report an emission factor in the registration form. Resume attachments, on the other hand, do not contain emission factors since these are created by AENV staff and not by the companies. The emission factors are available directly from the engine manufacturers or from the US EPA through source classification codes (SCC). It should be noted that these factors are only estimates because the volume of emissions can vary during operation depending on other factors such as elevation or efficiency of the engine

(which can diminish over time). Because emission factors were not included on the resume attachments, they were calculated using the same method used to calculate the misreported emissions, with a slight rearrangement. Equation 4 shows the altered formula.

Equation 4:

$$EF = [ER \times (1 \times 10^6) / 24] / [RP]$$

where,

EF	=	Emission factor (g/kW-h)
ER	=	NO_x emission (t/d)
RP	=	Rated power (kW)

Note: divided by 24 to convert days to hours
multiplied by 1×10^6 to convert tonnes to grams

The fourth and last data field in the database that is related to NO_x emissions is the Low NO_x field. Companies report in this field as a yes or no with regard to the engines they are reporting. Any engine that has an emission factor below 6 g/kW-h is considered to be a low NO_x engine. Again, this information is only provided on registration forms but, since it is known that engines must be below a certain emission factor to be considered low NO_x, this field could easily be updated.

The four fields mentioned in this section are important to the compressor engine database because together they provide pollutant information for each engine. The database contains several data fields that pertain to each device; this allows required information to be retrieved. For example, users are able to find specific engines from specific facilities and inquire about NO_x emissions or whether emission reduction technologies are in use.

5.0 NO_X EMISSIONS INVENTORY

5.1 Methods

There are several different ways to estimate NO_x emissions when continuous emission monitoring data are unavailable. Two possible measures are using either fuel consumption or operating time along with an emission factor. In this study, the provincial total of NO_x emissions was calculated using the total fuel consumed by devices at batteries, gathering systems, and plants. It is assumed that NO_x emissions from the upstream oil and gas sector are from these three sources.

The fuel usage data for the year 2000 were obtained from the EUB to which industry reports on a monthly basis for each facility. This data is gathered in specific "S" statements: S2 for batteries, S8 for gathering systems, and S20 for plants. The "S" statements are explained in Guide 7 of the EUB (2001); each statement is designed to provide basic operation information for each facility. There are some differences in the terminology used for fuel in the three reports used. The S2 reports "Gas Fuel", which corresponds to the fuel used at the facility, while the S8 reports it as "System Fuel". The S20 has two fuel headings – "Residual" and "Overhead"; the former refers to fuel used in plant operations. Table 6 shows the total volume of fuel consumed by each of the three types of facilities. Figure 5 is a graphic representation of the fuel use data provided in "S" statements.

Figure 5 **Distribution of fuel use by facility type in Alberta's upstream oil and gas industry (EUB Guide 7 – S2, S8, and S20)**

Plants use the most fuel since they usually house more equipment and devices than batteries. Gathering systems use the least fuel but not much less than batteries. However, it is expected that gathering systems emit far more NO_x than either batteries or plants since they contain mostly reciprocating compressor engines and no heater or boilers, and emission factors for reciprocating compressors are much higher. The data are presented in millions of cubic metres. CAPP (1999) found that the total amount of fuel burned in the upstream oil and gas sector in 1995 was 10 804 million cubic metres. Their source was the EUB Guide 7 "S" reports from 1995. The total we are using from the same source but for the year 2000 is 9703 million cubic metres.

Table 6 Fuel Distribution Volume for Each Facility Type ($10^6 m^3$), year 2000

	Batteries	Gathering Systems	Plants	Total
Reciprocating Compressors	1 014.22	2 483.52	1 288.51	4 786.25
Gas Turbines	32.69	130.71	644.26	807.66
Heaters and Boilers	1 747.08	0.00	2 362.27	4 109.35
Total	2 793.99	2 614.23	4 295.03	**9 703.25**

Also required for the emissions estimate is the emission factor for each type of device. The emission factors were taken from CAPP (1999) (Table 1), and were originally adapted from AP-42 (US EPA, 1995). These were discussed in section 3.5. The units used for the rate are kilograms of NO_x per million cubic meters of natural gas burned. The emission factor for natural gas–fired reciprocating compressor engines is 45 500 kilograms of NO_x per million cubic metres of natural gas burned. The emission factor for gas turbines, using the same units, is 5725; the emission factor for heaters and boilers is 4213. Equation 5 shows how the NO_x emissions were calculated.

Equation 5:

$$ER = FC \times EF$$

Where:

ER = Emission rate (t/y)
FC = Fuel consumption ($10^6 m^3$ of fuel)
EF = Emission factor ($kg/10^6 m^3$ of fuel)

Note: conversion of kilograms to tonnes – Divide by 1000

Since the total fuel used is divided up by type of facility it also has to be divided up by device. This means that a ratio must be assigned to each of the devices since the fuel may not be evenly distributed. Table 6 shows how the fuel use was apportioned at each

facility. At batteries, compressor engines used 36% of the fuel while heaters and boilers used 63%. There are very rarely any gas turbines at batteries and therefore only 1% of the fuel was attributed to them. Gathering systems have no heaters or boilers and 95% of their fuel usage is attributed to reciprocating engines and 5% to gas turbines. Gas plants have all three types of devices but use most of their fuel for heaters and boilers. This might be attributed to the functionality of the plant in areas such as space heating. Reciprocating engines use 30% of the volume of fuel used at plants and gas turbines use 15%.

The ratios in Table 7 are derived from CAPP (1999) and (AE, 1990). CAPP (1999) divided up the total amount of fuel burned into several categories. Since we are only using three specific emission sources (batteries, gathering systems, and plants), some of their categories were grouped together. For example, CAPP (1999) divided plants into four sub-groups: sweet gas plants, sour gas plants-flaring, sour gas plants-recovery, and reprocessing plants. The average was taken from each of the four types of plants to determine the distribution ratio for all plants as used in Table 7. The ratio for gathering systems was taken from AE (1990) because CAPP (1999) separated gathering systems into several categories that included other facilities as well.

Table 7 Fuel Distribution Ratio for Each Facility Type

	Batteries	Gathering Systems	Plants
Reciprocating Engines	0.36	0.95	0.30
Gas Turbines	0.01	0.05	0.15
Heaters and Boilers	0.63	0.00	0.55

Another source of NO_x emission in the oil and gas industry is compressor engines along pipelines, which are commonly gas turbines. This does not include the pipelines used in gathering systems, but rather the pipelines used to transport refined product to users. These pipelines are part of the downstream oil and gas sector. Transmission fuel is not likely included in the "S" files and is estimated to emit roughly 10 000 t/y of NO_x. CAPP (1999) documented that transmission systems emitted 10 044 t in 1994, 10 312 in 1995, and 10 744 in 1996. Since this study is focused on estimating the NO_x emissions from the upstream oil and gas industry, transmission systems are not included. However, it should be noted that transmission pipelines are responsible for a significant portion of NO_x emissions and should be considered in a province-wide total pollutant inventory.

5.2 Estimated NO_x Emissions from Reciprocating Engines

Natural gas–fired reciprocating compressor engines are the greatest NO_x emitters in the oil and gas industry. Two reasons for this are that they can have very high emission factors and are used more commonly than gas turbines. Reciprocating engines are used

93% of the time where compression is required. They also consume 49% of the fuel burned in the upstream oil and gas industry. Table 8 shows the volumes of emissions from reciprocating engines at each type of facility as well as a total volume. The method used to derive the final value was described in the previous section (equation 5). Reciprocating compressor engines were responsible for 91% of the NO_x emissions, which amounted to 217 774 t in 2000.

Table 8 NO_x Emissions from Reciprocating Compressors in the Upstream Oil and Gas Industry

	Total Fuel Use ($10^6 m^3$)	Emission Factor ($kg/10^6 m^3$)	Total NO_x Emissions (t/y)
Batteries	1 014.22	45 500	46 146.88
Gathering Systems	2 483.52	45 500	113 000.16
Plants	1 288.51	45 500	58 627.23
Total	4 786.25		**217 774.27**

5.3 Estimated NO_x Emissions from Gas Turbines

Gas turbines are not very common in the upstream oil and gas industry. They use 8% of the fuel burned and account for only 7% of all compressor engines. It was expected that, because of their emission reduction technology and small numbers, gas turbines would not contribute a significant amount of NO_x emissions to the provincial total. Gas turbines emitted 4624 t of NO_x in 2000, which is only 2% of the provincial total. Table 9 summarizes how the NO_x emissions estimate was calculated as per equation 5. It also breaks down the emissions by type of facility.

Table 9 NO_x Emissions from Gas Turbines in the Upstream Oil and Gas Industry

	Total Fuel Use ($10^6 m^3$)	Emission Factor ($kg/10^6 m^3$)	Total NO_x Emissions (t/y)
Batteries	32.69	5 725	187.15
Gathering Systems	130.71	5 725	748.32
Plants	644.26	5 725	3 688.36
Total	807.66		**4 623.83**

5.4 Estimated NO_x Emissions from Heaters and Boilers

Heaters and boilers were not included in the database since they were outside the scope of this study. However, as mentioned above, in estimating the NO_x emissions from

compressor engines, the amount of fuel burned by heaters and boilers is subtracted. Also the emission factor for heaters and boilers is given in Table 1, from where the compressor engine emissions factors were taken (CAPP, 1999). Heaters and boilers were included in our emissions estimate even though they were not part of the database. Heaters and boilers account for the remaining NO_x emissions in the upstream oil and gas industry and are an integral part of the total estimate. They burn 42% of the fuel used in the industry but have a very low emission factor compared to that of reciprocating compressor engines. Their total NO_x emissions in 2000 were 17 313 t which is 7% of the total. Heaters and boilers are not used in gathering systems as shown in Table 10. The table also shows the emission estimate calculation method, which is also broken down by type of operation.

Table 10 NO_x Emissions from Heaters and Boilers in the Upstream Oil and Gas Industry

	Total Fuel Use (10^6m^3)	Emission Factor ($kg/10^6m^3$)	Total NO_x Emissions (t/y)
Batteries	1 747.08	4 213	7 360.45
Gathering Systems	0.00	4 213	0.00
Plants	2 362.27	4 213	9 952.24
Total	4 109.35		**17 312.69**

5.5 NO_x Emissions from the Upstream Oil and Gas Industry

Figure 6 is a graphic representation of the total NO_x emissions broken down by source; it shows the emissions from each type of facility in the upstream oil and gas sector. The NO_x emissions estimate was determined using emission factors and fuel usage volumes. The fuel usage data were broken down into the three sub groupings used in Figure 6 and although plants use the most fuel, gathering systems have the highest NO_x emissions.

Table 11 is a summary of the NO_x emissions from each source. The data in this table do not break down the emissions by type of facility but rather show the total NO_x emissions by each type of device. The table shows just how small the emissions are from gas turbines and heaters and boilers compared to reciprocating compressor engines. The NO_x emissions from the upstream oil and gas industry for the year 2000 were found to be 239 711 t by this study. This value is comparable to 1995 emission inventories. CAPP (1999) reported the emissions to be 232 048 t in 1995 while Environment Canada (1996) reported 255 712 t.

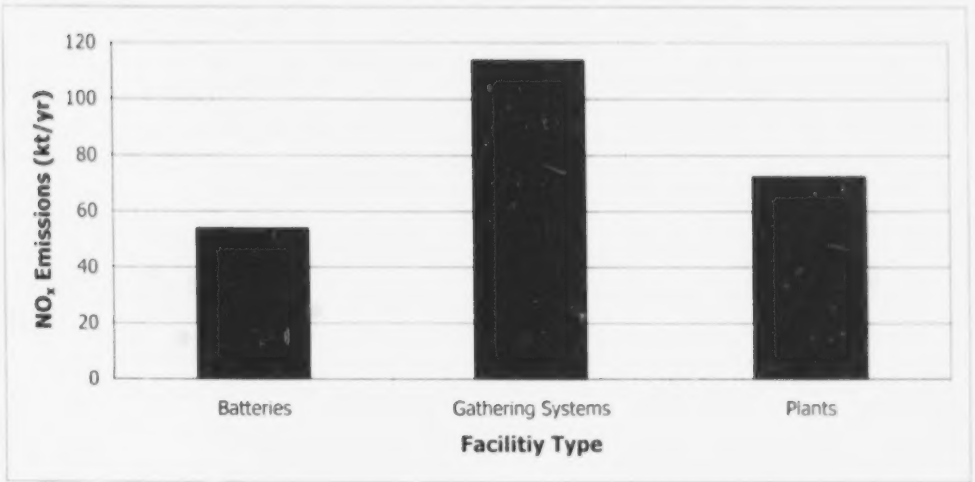

Figure 6 **NO_x emissions from each type of facility in Alberta's upstream oil and gas industry**

Table 11 **NO_x Emissions from all Sources in the Upstream Oil and Gas Industry**

	Total Fuel Use (10^6m^3)	Emission Factor ($kg/10^6m^3$)	Total NO_x Emissions (t/y)
Reciprocating Engines	4 786.25	45 500	217 774.27
Gas Turbines	807.66	5 725	4 623.83
Heaters and Boilers	4 109.35	4 213	17 312.69
Total	9 703.25		**239 710.79**

As mentioned in section 2, previous inventories may serve useful as a check against the findings of this study. Figure 7 is a graphic representation of the estimated NO_x emissions reported by three studies in previous years in comparison to the findings of this inventory.

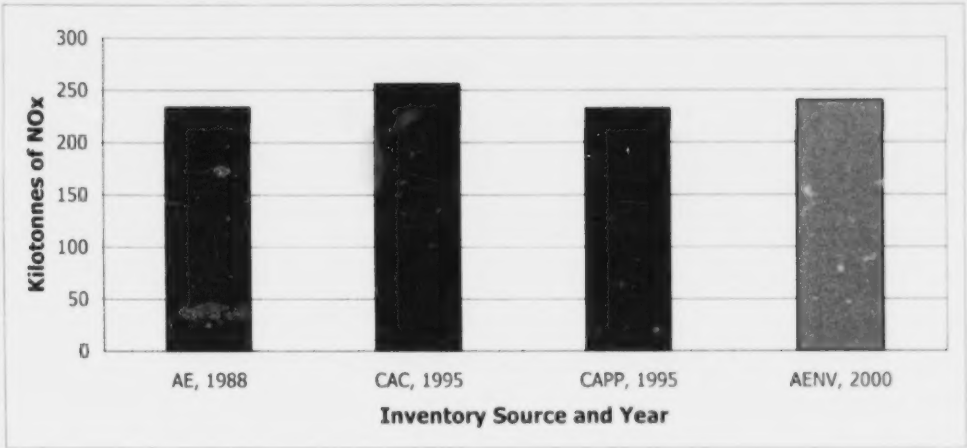

Figure 7 Comparison of the present NO_x emission inventory from Alberta's upstream oil and gas industry with previous studies

A trend over time cannot be assessed since the methodologies used for each study were different. The emission factors used in the emissions estimate calculations also vary, making a trend even more difficult to infer. However, it can be seen that the range of variability between all of the studies is fairly small and, since our estimate lies within that range, it is assumed to be an adequate representation of NO_x emissions from the upstream oil and gas industry.

5.6 Spatial Allocation of Emissions in Alberta

Once the NO_x emissions estimate was completed, it was useful to illustrate how the pollutant is spatially distributed. There are several regions of Alberta that have more oil and gas development than others and are therefore expected to produce higher NO_x emissions. The figures found in the maps section at the end of this report do not represent ambient air; their purpose is to geographically demonstrate where NO_x emission sources from the upstream oil and gas industry are most prominent. Maps 1 and 2 show the aggregate emissions from all facilities found within the chosen grid cells. Both maps were produced using the same methodology but differ in that Map 1 is based on a consistent grid cell size while Map 2 uses the Canadian census tract divisions as its grid cells. Map 3 shows the point sources that are contained in the compressor engine database discussed in section 4 of this report. It should be noted that this map does not include all oil and gas facilities in Alberta, rather only those that are regulated by Alberta Environment. Map 3 was created as a check for Map 1 to ensure that the spatial allocation of emissions was consistent with facility locations. The spatial allocation of data was performed using ArcView V.8.1 Geographic Information System (GIS).

Map 1 is a figure of Alberta showing NO_x emissions apportioned to grid cells. Each grid cell is 0.1 degrees latitude by 0.2 degrees longitude, which is approximately a 12 km by 12 km area. The same methodology used for the emissions estimate was applied here. For example, if a grid cell contained two facilities, the NO_x emissions from both sources were summed. To estimate the NO_x emission from each facility another calculation was required. The "S" statement information provided by the EUB contained 'per-facility' fuel use and location information. Using the fuel distribution ratios from Table 7, the CAPP emission factors from Table 1, and the volume of fuel used at each facility, NO_x emissions per facility were estimated. Equation 6 shows how this calculation was performed.

Equation 6:

$$ER = FC \times EF \times FR$$

Where:

ER	=	Emission rate (t/y)
FC	=	Fuel consumption ($10^6 m^3$ of fuel)
EF	=	Emission factor ($kg/10^6 m^3$ of fuel)
FR	=	Fuel distribution ratio

Note: Conversion of Kilograms to Tonnes – Divide by 1000

The facilities were then overlain onto the map with the grid cells. Since the NO_x emissions for each facility were known, a total NO_x emission per grid cell could be determined. As seen in Map 1, there are several shades each indicating the magnitude of NO_x emissions in the grid cells. The method outlined above was used to allocate NO_x emissions to grid cells using the point source data as a surrogate.

The same process described above was used to create Map 2, which represents emissions allocated to Canadian census divisions in Alberta. This map identifies the mass of NO_x pollutants produced in each census tract by the upstream oil and gas industry in Alberta. For the purposes of this figure, the census divisions act as individual grid cells. Using the same methodology described above, the total emissions from each grid cell were calculated. The difficulty in making any assessments from this map is that the grid cells are not uniform in size. Census divisions 16 and 17 together account for close to half of the province's area and would be expected to demonstrate higher emissions than any other tract. This holds true for census division 17 but not for 16. This is probably due to a large portion of division 16 being Wood Buffalo National Park. Other useful observations would be the higher emissions in the region west of Edmonton (census divisions 9, 11, 14, and 18), in the Cold Lake region (census division 12), and in the Medicine Hat region (census division 1). All three of the listed observations are consistent with the spatial allocation of emissions seen in Map 1 and are also regions known for their oil and gas operations. Table 12 presents the data shown in Map 2.

The information contained in the compressor engine database includes the geographic coordinates of each facility. Map 3 shows the point sources of these coordinates in Alberta. As mentioned in section 4, the database only includes individual facilities that are regulated by Alberta Environment. Also shown on the map is the oil and gas pipeline network, obtained from the EUB, in Alberta. The pipeline network is fairly dense in some regions of the province. To produce a figure that was legible, only those pipelines greater than 200 mm in diameter are shown on the map. There are 535 facilities depicted in the figure, each of which may have several emission sources (devices) on-site. However, since the map is a source characterization, each facility is identified by a single point. The distribution of facilities is consistent with the pipelines and the spatially allocated NO_x emissions for all upstream oil and gas facilities as shown in Map 1.

Table 12 NO_x Emissions from Alberta's Upstream Oil and Gas Industry by Canadian Census Divisions

Census Division	NO_x Emissions (t/y)
Division No. 1	16 922
Division No. 2	10 492
Division No. 3	6 474
Division No. 4	8 271
Division No. 5	9 713
Division No. 6	9 791
Division No. 7	6 945
Division No. 8	8 444
Division No. 9	15 953
Division No. 10	9 030
Division No. 11	11 109
Division No. 12	30 246
Division No. 13	10 569
Division No. 14	11 465
Division No. 15	1 779
Division No. 16	12 931
Division No. 17	38 420
Division No. 18	11 589
Division No. 19	9 550

6.0 CONCLUSION

This study had two objectives: to produce a database of compressor engines and to estimate the NO_x emissions from Alberta's upstream oil and gas sector. Both of these objectives were successfully achieved. The database was created in MS Access and contains both reciprocating compressor engines and gas turbines that are regulated by Alberta Environment. Although the database does not include all the engines in use in the province, it was assumed to provide a representative sample from which the current state of compressor engines in the industry could be examined. Heaters and boilers are also a source of NO_x emissions from upstream oil and gas operations, and although they are included in the emissions estimate, they are not part of the database.

In the database of AENV regulated facilities, it was also found that 24% of all the engines use low NO_x technology, which means that they have an emission factor lower than 6g/kW-h. Many rich-burn engines can emit NO_x at a rate higher than 24 g/kW-h. Another interesting finding is the ratio of turbine engines to reciprocating engines. Only 7% of all engines are turbines and, although they generally produce a large amount of power, their emissions are not usually higher than those of reciprocating engines. The compressor engine database served as a tool for assessing the roles of particular technologies in the upstream oil and gas sector.

The impact of reciprocating compressor engines on total NO_x emissions is also important. Although plants use the most fuel, it is gathering systems that emit the most NO_x. This can be attributed to the absence of heaters and boilers at gathering systems. It is estimated that heaters and boilers consume more than half the fuel burned at plants and their emissions are lower than those from reciprocating compressor engines by a factor of 10.

Furthermore, the database showed that 27% of compressor engines use low NO_x technology. Most gas turbines possess low NO_x technology while only 22% of reciprocating compressor engines are equipped with it. NO_x emissions from reciprocating compressor engines account for 91% of the total found in this study. There is potential for this source of NO_x emissions to be reduced substantially in the face of the national total if new technology continues to be implemented.

The data contained in the compressor database do not form a complete set of engines. The study would have many more applications if all compressor engines were documented, including those regulated by the EUB. AENV regulates a small subset of those facilities regulated by the EUB; it might be useful to compare the EUB data against the database as a check for the validity of information reported to AENV. Furthermore, some of the assumptions made in this study could be reviewed in more depth. For example, the distribution of fuel consumption between devices could be surveyed at actual facilities. Also, the emission factors used could be checked for accuracy in comparison to actual operating engines where other variables are taken into consideration such as elevation and/or climate. An additional enhancement for this study is statistical

testing for the reliability of the data. It would be beneficial to know the degree to which the information is valid and for which population the assumptions hold true.

It is expected that future inventories for the 2000 base year will make use of the findings in this study. The scope of this project was limited to the upstream oil and gas industry in Alberta. It is recommended that future studies adopt a more comprehensive approach by taking into consideration several other sources that were beyond the scope of this project. One such source that was not accounted for in this study was the emissions from gas transmission engines, which are the jurisdiction of the National Energy Board. These engines are not part of the upstream oil and gas sector but are of interest since they are thought to emit upwards of 4000 t/y of NO_x.

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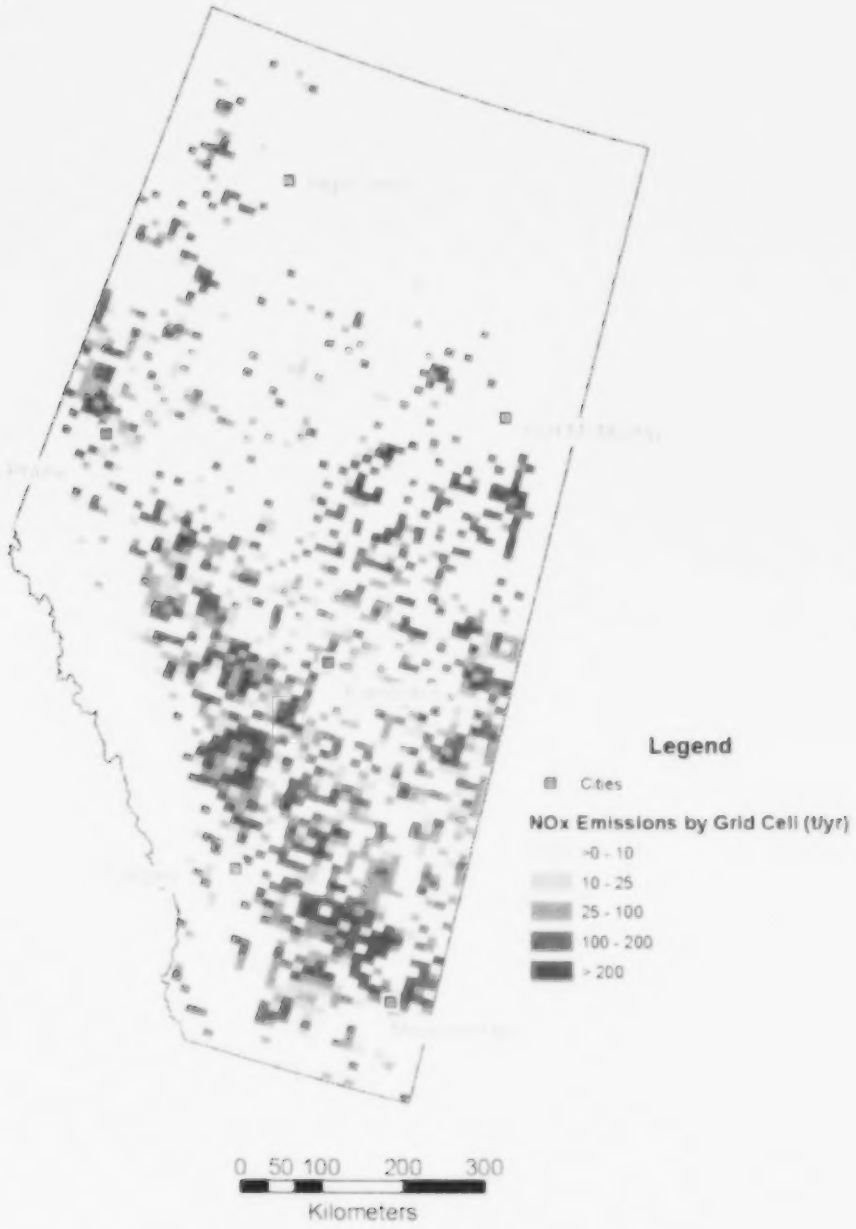
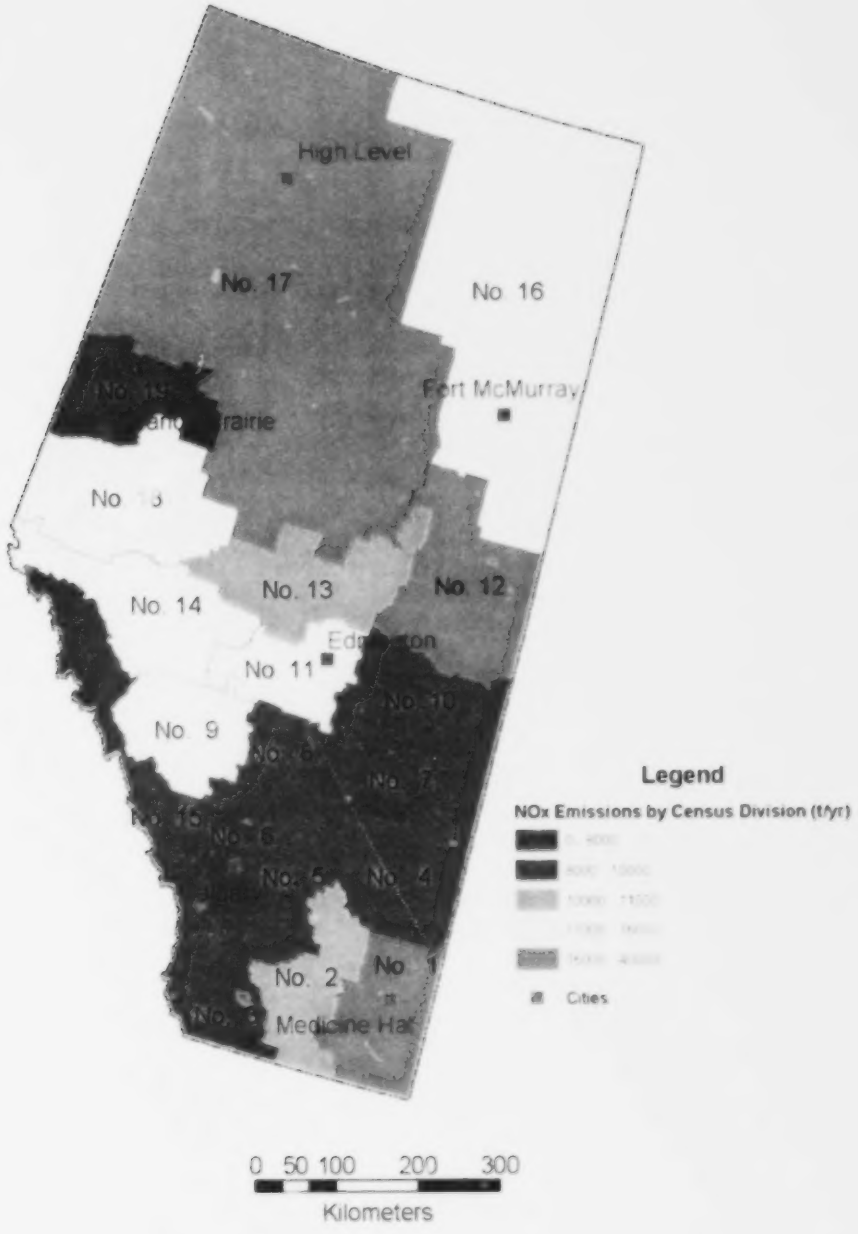
MAPS

The following maps are referred to as Maps 1 through 3. These were created using ArcView V.8.1. Geographic Information System (GIS). The methods used to generate the maps are described in section 5.6.

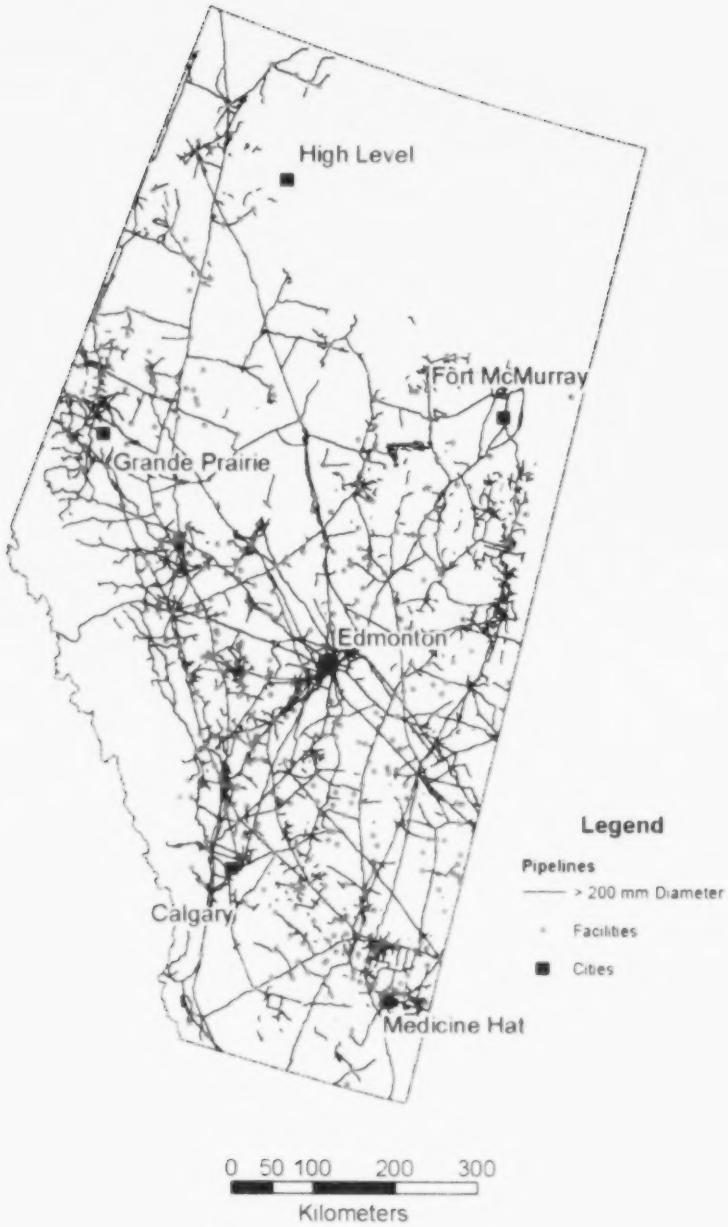


Map 1 **NO_x emissions from Alberta's upstream oil and gas industry for the 2000 base year. Selected cities are shown for reference.**



Map 2 **NO_x emissions from facilities in Alberta's upstream oil and gas industry shown by Canadian Census Divisions for the 2000 base year. Selected cities are shown for reference.**

Map 2 **NO_x emissions from facilities in Alberta's upstream oil and gas industry shown by Canadian Census Divisions for the 2000 base year. Selected cities are shown for reference.**



Map 3 **Facilities in Alberta's upstream oil and gas industry that are regulated by AENV as of December 2001. Selected cities are shown for reference.**

APPENDIX

The following are examples of actual forms that contain the information about specific facilities regulated by Alberta Environment. Figure 11 is a Compressor and Pumping Station/Sweet Gas Processing Plant Registration form, Figure 12 is an Industrial Facility Approval Resume, and Figure 13 is an Air Emissions Branch Attachment. All three forms were arbitrarily chosen and have no significance with regard to the facilities identified on them. Descriptions of these forms can be found in section 4.3.

COMPRESSOR AND PUMPING STATION/SWEET GAS PROCESSING PLANT REGISTRY FORM

1 ADMINISTRATIVE

Company Name: (legal incorporated name) Anderson Exploration Ltd.
Operating Name: (if different than above) Same
Mailing Address: 1600, 324 Eighth Avenue S.W. Calgary, Alberta T2P 2Z5
Plant Name: Anderson Normandville Gas Plant
Legal Land Description: 13-09-79-22 W5M
Contact Person: Jerry Mazurek
Phone Number: (403) 359-2650
Fax Number: (403) 359-2100

2 APPROVALS

(a) Has the station/plant ever previously received an environmental approval? If so, provide the approval number: 93-AL-107

(b) Have there been any equipment changes since the issuance of the approval that affect substance release to the environment? N Y/N

Provide information (or amendment information) as requested in Section 3 & 4

3 AIR EMISSION EQUIPMENT INVENTORY/STACK (INITIAL AND/OR AMENDMENT) DATA

Source ID & Type (Including engine make & model no.)	# of Sources	Rating (kW)	Low NO_x Engine (Y/N)	NO_x Emission Factor (g/kW*hr)	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Exit Temperature (°C)	NO_x Emission (tonnes/day)
Superior 12G825 Turbocharged Natural Gas Engine	1	895	N	20.1	12.2	0.31	44.1	650	0.432 tonnes/day
Waukesha 3521 GSI Turbocharged Aspirated Gas Engine	1	550	N	24.2	9.1	0.22	51.1	590	0.31968 tonnes/day
Glycol Heater Exhaust Stack	1	219	N/A	0.355	5.2	0.32	2.0	673	0.002 tonnes/day
Emergency Flare Stack*	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Space ventilation exhaust vents*	Lot	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Space heater exhaust vents*	Lot	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Compressor starter gas vents*	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* Information only

Maximum Ground Level Concentration (MGLC) NO_2: 0.086 PPM
Dispersion Model Used: SEEC-VI
Total NOx Emission: 0.7537 (tonnes/day)
Processing/Compression Capacity: 354,000 m^3/day

Example Form 1 **Example Compressor and Pumping Station/Sweet Gas Processing Plant Registration form (Page 1 of 2)**

4 INDUSTRIAL WASTE WATER (OR AMENDMENT INFORMATION) REQUIREMENTS

ITEM	CONTENTS	VOLUME (m^3)	LINER SYSTEM	G/W MONITORING	DESCRIPTION
Landfill	N/A	N/A	N/A	N/A	N/A
Pit	N/A	N/A	N/A	N/A	N/A
Pond	N/A	N/A	N/A	N/A	N/A
Lagoon	N/A	N/A	N/A	N/A	N/A

I acknowledge that I have reviewed a copy of the Code of Practice for Compressor Pumping Stations and Sweet Gas Processing Plants and that I am bound by the provisions of this Code of Practice, and any subsequent amendments to it.

Signature of Person Responsible — Date: MARCH 12/97

For office use only

Date Received: March 21 1997
Registered by:

David Spink, Director Air & Water Approvals — Director's Signature/Title — Date: March 21/97

Registration Number: 11501

Example Form 1 **Example Compressor and Pumping Station/Sweet Gas Processing Plant Registration form (Page 2 of 2).**

INDUSTRIAL FACILITY APPROVAL RESUME

DESCRIPTION

APPROVAL NO.: 139549-00-00 **EXPIRY DATE**: April 1, 2011	**APPLICATION NO.**: 001-139549 **DATE RECEIVED**: Sep. 14, 2000	**OLD APPROVAL NO.**: **EXPIRY DATE**:
APPROVAL HOLDER: Magin Energy Inc.		**AENV CORPORATE REGION**: Parkland
FACILITY NAME: Pembina Sour Gas Processing Plant		**LOCATION (Municipality)**: Warburg
ACTIVITY DESIGNATION (Schedule 1): Sour Natural Gas Processing Plant		**LLD**: 10 14 048 03 W5M
WAS THERE AN EUB DECISION FOR THIS PROJECT: ☐ N/A ☒ Yes ☐ No		**DECISION REPORT NO.**

APPLICATION TYPE	NOTICE	TYPE OF ADVERTISEMENT	
		NEWSPAPER/OTHER	DATE
New/Initial / Non-Routine	☐ DECISION (Attach waiver form)		
	☒ APPLICATION	*Drayton Valley Western Review*	Dec. 12, 2000

JOINT NOTICE: ☒ N/A ☐ Water Act ☐ EUB

NO. OF SOC: 0 | **COMMENTS ON SOC**: N/A | **LEGAL ADVICE**: ☒ Yes ☐ No

APPLICATION COMPLETE FOR PURPOSES OF PUBLIC NOTICE AND REVIEW ☒ Yes **DATE**: Dec. 7, 2000

SUPPLEMENTAL INFO REQUESTED: ☒ Yes ☐ No **DATE REQUESTED**: 2/23/01 **RECEIVED**: February 28, 2001

GENERAL DESCRIPTION OF THE FACILITY (raw materials, product, nominal production capacity, process, costs)

Plant capacity – 141.6 x 103 m3 / d.
MDEA amine sweetening skid – 1.55 SO2 t/d flaring.
Refrig skid – tied into low pressure flare.
Emergency flare fuel gas source – downstream pipeline ESD bypass.
400 bbl tank fuel gas blanketed, vent to low pressure flare.

Make-up water to be trucked in.

Industrial wastewater to be trucked off-site.

Waste to be disposed of in accordance with EUB Guide 58.

Topsoil to be removed and stored out of runoff area.

400 bbl tank and MDEA/glycol skids to be 2nd contained and monitored.

No runoff control.

APPROVAL REQUIREMENTS

	Sources and Controls/Management	Monitoring and Frequency	Reporting	Attachments
Air Emission	Flaring plant	2 ambient passives + emissions	☒	☐
Wastewater	Trucked offsite	Annual information to be recorded & retained	☐	☐
Waste	N/A	N/A	☐	☐
Domestic Wastewater	Not on-site	N/A	☐	☐
Waterworks	Not on-site	N/A	☐	☐
Groundwater	Basic GW program	As accepted in writing by Director	☒	☐
Soil	Basic soil program	As accepted in writing by Director	☒	☐
Land Conservation and Reclamation	Topsoil to be placed out of runoff area	N/A	☐	☐
Other/Special			☐	☐

Example Form 2 Example Industrial Facility Approval Resume (Page 1 of 2).

APPROVAL NO: 139549-00-00

APPLICATION NO: 001-139549

APPROVAL REQUIREMENTS

COMMENTS: (Important history background, critical issues, points for future consideration, enforcement action, etc.)

Plant is 0.7 km from Strawberry Creek. As this is a new plant and all equipment will be secondarily contained, the soil and groundwater monitoring will be used to activate surface water runoff control.

The stack modelling indicates a maximum ground level SO_2 concentration of 295.3 $\mu g/m^3$ at approximately 320 m from the plant.

The modelling indicates a maximum ground level NOx concentration of 23.8 $\mu g/m^3$ at approximately 10 m from the plant.

SECTION 61 EPEA CONSIDERED: ☒ Yes ATTACHMENTS: ☐ Yes ☒ No

REFERRAL

APPLICATION		DRAFT APPROVAL		
Head Office: ☐ Yes ☒ No Subject Area:	Other:	Applicant: ☒ Yes ☐ No	SOC Submitters: ☐ Yes ☒ No	Legal: ☐ Yes ☒ No

ADMINISTRATION

DRAFT NOTICE OF DECISION ATTACHED: ☐ Yes ☒ No

ALSO SEND SIGNED APPROVAL TO:

ADMINISTRATIVE REVIEW:	APPROVAL COORDINATOR: RECOMMENDATION TO ISSUE APPROVAL	APPROVAL MANAGER:
KAM	KAM	LAW

Example Form 2 Example Industrial Facility Approval Resume (Page 2 of 2).

APPROVAL NO. 151821-00-00
APPLICATION NO. 001-151821

AIR EMISSIONS ATTACHMENT

Approval Holder: Anderson Exploration Ltd

Facility: Rycroft Sour Gas Processing Plant **File No.:** 151821-00-00

EMISSION DATA:	**TOTAL NO_x:**	0.203 t/d	
	TOTAL SO_2:	0 t/d (Normal Operation)	t/hr

FACILITY STATUS: NEW	**ENV. SETTING:** RURAL	**TREE HT:** 10 **M**	**SITE ELEV.:** 657 **M**

STACK DATA

Source ID # & Type	#	Rating (kW)	Stk. Dia. (m)	Stk. Ht. (m)	EXIT		POLL	*Approved Conditions EMISSIONS	
					Vel. (m/s)	Temp. (°C)		(t/d)	(x 10^{-3} m^3/s)
Waukesha 7042GL Sales Gas Compressor Recip. Engine	2	1102.1	0.343	6.9	41.73	376.11	NO_x	0.0532	0.317
Waukesha H24GL Generator Recip. Engine	3	400	0.203	7.011	41.06	448	NO_x	0.0265	0.158
Parker T-5700 Glycol Heaters (3 heaters, 2 stacks/heater)	6	1335	0.546	5.9	2.58	176.7	NO_x	0.0029	0.017
Process Emergency Flare Stack	1	N/A	0.324	45.7	N/A	N/A	SO_2	N/A	N/A
Acid Gas Emergency Flare Stack	1	N/A	0.1683	45.7	N/A	N/A	SO_2	N/A	N/A

MONITORING REQUIREMENTS:

Stack Surveys:	N/A	**Soil pH:**	N/A
Static Exposure Stations:	N/A	**CEMS:**	N/A
Ambient Monitors:	N/A	**for:**	N/A
for:	N/A		

REPORTING: As per AMD

Example Form 3 Example Air Emission Branch Attachment.